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NATIONAL PHOTOGRAPHIC
INTERPRETATION CENTER

TEST AND EVALUATION REPORT

[redacted] TWIN STAGE ON-LINE P.I. COMPARATOR

25X1

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NPIC/R-54/71
DECEMBER 1971

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Test and Evaluation Branch
Engineering Support Division
Technical Services Group

NATIONAL PHOTOGRAPHIC INTERPRETATION CENTER

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ABSTRACT

The Twin Stage On-Line Comparator, designed and fabricated [redacted] has been tested for compliance to NPIC specifications and found generally adequate for its intended task although it does not comply in all details. In addition to the acceptance tests, performance and engineering tests were conducted to determine overall equipment characteristics. 25X1

During initial testing the general design and workmanship was found to be very good. However, the stage motion control and optical system required several modifications, including the addition of handwheel stage controls, installation of thinner film hold-down platen frames, adjustment of the fine focus control and a check of optical elements for possible defects causing resolution values slightly below those specified.

These changes and adjustments significantly improved the operation of the comparator, but the resolution and fine focus capabilities remain slightly below contract requirements. It is doubtful that corrective measures would repay the effort required.

A human factors evaluation, performed [redacted] noted mainly that several controls were incorrectly labeled or not labeled at all. In addition, TEB investigators noted a focusing linkage anomaly which makes focusing awkward under certain conditions. The general configuration of the comparator conforms to operator dimensional requirements. 25X1 25X1

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1. INTRODUCTION

1.1 Background

The Twin Stage On-Line Comparator (TSC) [redacted] is designed to provide the P.I. with the capability of obtaining precise measurement as a part of routine photointerpretation. Emphasis is placed on ease of operation, reliability, simplicity, and measuring accuracy. In addition to the capability for monoscopic mensuration, the TSC is designed to accomplish on-line stereo mensuration. The instrument was developed by TSG/RED for use by IAS. 25X1 25X1

The comparator was delivered on 27 October 1969. Following initial testing, an interim test and evaluation report was issued in March 1970, recommending certain modifications. These modifications were performed by [redacted] personnel at NPIC on 15 and 16 September 1970. 25X1

An interim test and evaluation report was published in March 1970.

The completed instrument is shown in Figure 1. Figure 2 shows the operators view of the console controls.

1.2 Test Objectives

Test plan objectives accomplished include: 1) specifications review, 2) notation and correction of problems, and 3) engineering and performance evaluations to assist in determination of specifications for follow-on procurement.

2. SUMMARY OF TEST RESULTS

2.1 Acceptance Tests

Acceptance testing was performed to determine whether the development objectives were met or not. The following paragraphs discuss some of the most important equipment characteristics examined. Detailed test data are provided in Section 5.

2.1.1 Overall Design. The overall design and construction are considered to be very effective and closely in accordance with correct human factors requirements.

2.1.2 Image Quality. The resolving power, field-of-view, and zoom focus capability are somewhat below specifications. However, the slightly low values were accepted as sufficient to meet operational requirements.

The prime specification on the optics was that the modified (extended) [redacted] Stereoviewer should retain 85% of the image quality of the unmodified instrument. Resolving power of the original optics at 200X magnification was measured to be 960 lp/mm; resolving power of the right optical path, after extension, is 761 lp/mm. This is below specification by less than one target element with 2^{-6} progression (See Table 1, Resolution Data.) 25X1

The field-of-view was specified to be that of the unmodified [redacted] Stereoviewer. Measurements show an average decrease to 85% that of the specified (not measured) field-of-view values. 25X1

Zoom focus requirements state that the image should remain in focus throughout the zoom range. In 6 of the 16 right-left eyepiece and objective lens combinations, however, the focus is not sharp throughout the zoom range of 1X to 2X magnification.

After initial readjustment of the optics, the right stage, focus control with 1.3X objective lens, still reaches the upper limit of travel just before good focus is achieved.

2.1.3 Film Platen. Requirements for the film hold-down platen were that the film would be held sufficiently flat over the entire format so that sharp focus would be maintained using the 1.3X and 3X objectives, and that at higher magnification (up to 200X) the film would remain in focus over 1 square inch. Both requirements were met.

2.1.4 Stage Motion. The stages move at speeds varying from .005 to 10 millimeters per second as required. However, at joystick deflections of 5 degrees or less in any direction the stage speed and direction are unpredictable. At larger joystick deflections, the direction of stage motion corresponds directly.

2.1.5 Measurement Accuracy. The manufacturer's calibration certificates (figures 3, 4, 5, 6) indicate that the accuracy requirements, for errors not greater than ± 2 micrometers for measurements under 1 inch, have been met.

2.1.6 Stage Orthogonality. A statistical evaluation of data obtained by making a series of measurements shows the non-orthogonality angle to be 3.5 ± 1.4 seconds of arc (95% Confidence Limits) for the right stage and $-.6 \pm 1.9$ seconds of arc (95% Confidence Limits) for the left stage, both values being within the ± 5 seconds of arc specification. (See Table 2.)

2.1.7 Human Factors. Film loading and unloading are somewhat difficult to accomplish as the upper film platens are not hinged and must be held out of the way during the loading or unloading process.

Labels have been omitted on the following items: 1) stage rotation hand cranks, 2) objective lens focus knobs, and 3) joystick and handwheel controls. The filter density selector switch has been incorrectly labeled as it reflects position (1, 2, 3, 4) rather than densities (0, .5, 1.5, 2.0).

The general configuration conforms to operator dimension requirements.

2.1.8 Film Gate Temperature Rise. During a 4 1/2 hour test a thermistor indicator, located under a 2.0 density film which was on top of the pressure platen, showed an average temperature rise of only 2.2 degrees F. A longer exposure is assumed not to produce a significant temperature difference.

2.1.9 Leakage Current. The leakage current of 8.5 ma, measured between the grounding conductor and earth ground, exceeds the USA Standard for Leakage Current for Appliances value of .75 ma.

2.2 Performance Tests

Performance tests were designed to explore the maximum capabilities of the comparator, in cases where specifications where not given.

2.2.1 Stage Motion Control. The primary stage motion control for relatively large displacements (0.3 mm or greater) is the joystick. For smaller displacement the handwheel controls provide increased control precision and permit more rapid pointing. (See Table 3.)

2.2.2 Illumination System. The substage illumination system provides approximately 200 foot-lamberts (fL) luminance to aid in film positioning.

The optics illumination system delivers a maximum of 28,500 fL on the left stage and 22,500 fL on the right. The difference is not noticed by the eye. (See Table 4.)

Luminance through the optics was measured to be in the order of 7-10 (apparent) fL.

2.3 Engineering Evaluation

2.3.1 Construction. The TSC has been rigidly designed such that physical vibrations do not cause visible image vibration, even at 200X magnification.

2.3.2 Backlash. The handwheel controls have some gear backlash, however, no measurement backlash (displacement difference vs. direction) was observed. If excessive hand pressure is exerted on the control wheels the film stages may be displaced without the position change being noted by the photo-electrical counters. An apparent position change in the order of ± 1 or 2 micrometers was observed on the right stage Y-axis, however, no change could be observed on the other 3 axes.

2.3.3 Drift. As both upper and lower glass platens are held only by frictional forces there is some potential for undetected target motion. A drift of approximately 9 micrometers occured during a 2-hour period. Vibrations probably cause the lower platen to shift within the frame.

2.3.4 Servicing. The electronics rack provides easy access to the chassis for servicing. Test points are not provided external to the chassis but are accessible by use of extender cards.

2.3.5 Pinch Point. If some part of the body was accidentally placed between the stages, physical injury could occur. The comparator might also be damaged if a hard object became wedged between the stages. Safe practice by the operator would probably avoid these potential hazards.

3. CONCLUSIONS AND RECOMMENDATIONS

The overall design and workmanship of the TSC is very good. Certain marginal characteristics were noted which do not really restrict the instrument in meeting design purpose. Operational use of the TSC is recommended.

4. DESCRIPTION OF EQUIPMENT

The TSC is comprised of 4 main systems: 1) stage motion and measurement, 2) illumination, 3) optics, and 4) electronics.

4.1 Stage Motion and Movement

The stage motion system is controlled by 5 functional controls: 1) a joystick which can be deflected up to 15° from vertical, 2) handwheel controls for independent fine positioning of both X and Y coordinates, 3) a rocker switch which determines whether the left, right or both stages move in response to joystick deflections, 4) stage speed ratio control which determines both the ratio, left stage speed to right stage speed or in reverse, and 5) stage master control that determines which stage is the master (maximum speed), allowing films of different scales to be viewed. Stage rotation is accomplished by means of a worm gear arrangement with a hand crank. Rotation is independent and continuous through 360°. These controls are on the comparator in easily reached and logical positions.

The direction of joystick deflection determines which of the velocity servo motors operates, either singly or in combination to produce corresponding displacements. The speed of motion is approximately proportional to the amount of joystick deflection. Stage displacement measurement is accomplished by electrical pulses generated by optical shaft encoders, which are coupled to the precision lead screws, which in turn drive the stages.

4.2 Illumination Source

The optical illumination source for each stage consists of a 100-watt tungsten halide lamp with a quartz envelope. The light is transmitted through a fiber optic bundle to a condenser lens which focuses on the film platen. A variable diaphragm, just before the fiber bundle, controls the light to match the four respective objective lenses. The lamp is controlled by a manual control which adjusts the lamp voltage from 0 to 100% of maximum.

Neutral density filters of nominal values .5, 1.0, 1.5 and one open gate position control the illumination level. Selection of the desired filter is made by rotating a control knob.

The entire film platen can be backlighted as an aid in positioning the area of interest under the optics.

4.3 Optics

The optical system is a [redacted] Stereocomparator Viewing system, modified to extend the left to right optical path separation to 18 inches. The Viewer has the following features in each optical path: 1) a four objective lens turret (1.3X, 3X, 6X, 10X), 2) a 1X-2X zoom, 3) fixed reticles, and 4) an optical image rotator continuously variable through 360°. Other viewer features are: 1) tilting eyepieces, 2) IPD adjustment from 55mm to 72mm, and 3) interchangeable eyepieces, 6X and 10X. 25X1

4.4 Electronics Console

The electronics package contains all power supplies, main switches, measurement readout display, pre-set and reset readout controls, and computer interface circuitry. The arrangement of the computer interface panel is identical to that of similar NPIC equipment.

The TSC can be used with either stereo or monoscopic NPIC mensuration programs by changing external cabling.

5. TEST DETAILS

5.1 Acceptance Tests

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION	
5.1.1 General				
Stage Aperature	The two photo stages shall be supported on separate X-Y carriages and have a face aperture of 6 by 6 inches.	Observed and measured stage aperture.	Left: X 152.4mm, Y 152.4mm; Right: X 152.4mm, Y 152.4mm	Satisfactory
Scale Differential	A differential drive shall be provided between the two stages to permit stereo scanning of film chips of two different scales.	Observed and measured stage displacement.	Ratios of approximately 1:1, 1:.8, 1:.6, 1:.4, 1:.2, are provided, however, stereo fusion cannot be maintained while scanning.	Unsatisfactory
Stage Movement	The movements of the X-Y carriages of both photo stages shall be measured by two digitizers (X and Y) with a measuring range of 6 inches in both X and Y directions.	Observed and measured stage displacement.	152.4mm for X and Y for both stages.	Satisfactory
Signal Format	The signals for the X-Y digitizers shall be processed and converted into a format acceptable for on-line computer use.	Trial mensuration exercise (monoscopic program).	Acceptable format.	Satisfactory
5.1.2 Details				
Separation Extension	The viewing system shall be a [redacted] High Power Stereo Comparator Head modified to permit increased separation of the two turret optical center lines to approximately 18 inches.	Observed and measured.	Approximately 18 inch separation.	Satisfactory
Focus	Independent fine focus adjustment shall be provided for each leg of the optical train.	Observed.		Satisfactory
Objectives	The contractor shall provide the following objectives with the instruments; two each: [redacted] Fluotar [redacted] 3.0X, [redacted] Fluotar [redacted] 6.0X, [redacted] Fluotar [redacted] 10X. Provision must be made to accommodate the [redacted] Special Order 1.3X objectives (GFE).	Observed.		Satisfactory

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5.1 Acceptance Tests (continued)

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ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
Eyepieces	The contractor shall provide the following eyepieces with the instrument; two each: [redacted] Compensating [redacted] 6X, [redacted] Compensating [redacted] 10X.	Observed.	Satisfactory
Reticle	A sharp round black reticle 20 micrometers in diameter shall be provided in both the left and right leg of the optical system.	Observed (not measured).	Satisfactory
Modified Image/ Quality	The image quality of the modified [redacted] High Power Stereoviewer Comparator Head will be no less than 85% of those values for an unmodified High Power Stereoviewer. These quality standards apply to all of the optical parameters. This means that the modified comparator shall have an optical quality of no less than 85% of the unmodified stereoviewer. This degradation includes any produced by the glass pressure plate.	Resolving Power: The resolving power of the optical system was checked by 3 observers using a high contrast, 240X reduction 1951 USAF target. (See Table 1, for complete resolving power data.)	*NOTE: Apparently no single adjustment of the optical elements would improve the resolving power. It was determined, however, that the values were sufficient. Unsatisfactory *(accepted)

Lens Combinations (Magnification) EYE	OBJ	ZM	Required Resolving Power (lp/mm)	Measured Resolving Power (lp/mm) Left (Stages)	Right
10	3	2	272	268.8	240.0
10	6	2	535	537.6	480.0
10	10	2	850	854.4	760.8

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
	The size of the field-of-view will equal that of the unmodified instrument.	Field of View: The field of view was measured by using the comparator as the measuring instrument. A line was transported from one extremity of the field-of-view to the other and the readings taken from the output display. An average of 3 X-Y values is used to compute the measured field-of-view.	See Field of View results below. Unsatisfactory (accepted)
	The image will remain in focus throughout the zoom range.	Zoom Focus: The zoom focus capabilities of the TCS were checked by focusing on a resolution target and then noting the focus as the zoom control moves through the range 1X to 2X magnification.	See Zoom Focus results below. Unsatisfactory (accepted)
5.1.3 Film Stage			
Film Size	There shall be two film stages capable of handling film chips in sizes up to 6 x 6 inches.	Observed.	Satisfactory
Independent Stage	Each of the film stages shall be supported on separate X-Y carriage assemblies.	Observed.	Satisfactory

Field of View results:

Lens Combinations (Magnification) EYE	OBJ	#Required Field of View (mm)	Measured Field of View (mm) Right	Left
6	1.3	14.0	11.15	11.32
6	3	6.0	5.08	5.33
6	6	3.0	2.50	2.62
6	10	1.8	1.54	1.58
10	1.3	14.0	11.09	11.46
10	3	6.0	5.12	5.41
10	6	3.0	2.53	2.63
10	10	1.8	1.55	1.60

#NOTE: The field-of-view measurements show an average decrease to 85% that of the specified (not measured) field-of-view values for the unmodified stereoviewer.

Unsatisfactory (accepted)

Zoom Focus results:

Combinations (Magnification) EYE	OBJ	Unsatisfactory Focus (+) Stage Left	Right
10	1.3	+	+
10	3		+
10	6		+
6	1.3	+	
6	3	+	

Unsatisfactory (accepted)

5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
Translation Range	Each of the film stages shall have independent translation of ±3 inches in both the X and Y axes.	Observed and measured.	Total Translation (both stages) X: 152.4mm Y: 152.4mm Satisfactory
Stage Protection	Appropriate warning signals and cut-off circuitory shall be provided to prevent damage to the film stages when they are on a collision course.	Observed.	The moving stages (inward) can come within 1/4 inch of each other before motion is stopped. An additional protection method may be beneficial to protect both the instrument and the user. Limit switches stop the stages at the extreme positions. Satisfactory
Stationary Optics and Illumination	The optical viewing system and the illumination source shall remain stationary (in X and Y).	Observed.	Satisfactory
Stage Rotation	Each stage shall provide 350° rotation capability of its film support surface about the center of the clear aperture.	Observed. Stage rotation is accomplished by the use of a worm gear drive and hand crank system.	Rotation 280 turns equals 360° rotation Hand crank radius is 3/4 inches. Satisfactory
Stage Speed	The range for both independent and common stage drive speeds shall be from no faster than five (5) micrometers per second to no faster than five (5) millimeters per second. A design goal shall be a maximum speed of 10mm per second.	A test was conducted to measure stage speed vs. joystick displacement. The conclusion was that the speed and displacement were not directly related. As a result the TSC was modified with the addition of handwheel controls which allow extremely slow stage speeds, such that a displacement of 1 micrometer can be made easily in either X or Y directions.	Stage Speed (Joystick Control) Maximum: 5mm/second Minimum: 5 micrometers/second Satisfactory
Flatness	Film holddown may be accomplished through glass pressure plates or other mechanical means, but it must be capable of maintaining the film flat and in sharp focus over the format. If a glass	The focus test consisted of observing focus conditions on a resolution target, moved to various positions over the format.	

5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
	pressure plate is used, its thickness shall not exceed .063 inch. The film platen and holddown system shall be such that it will maintain the film in sharp focus over the entire format using the 1.3X and 3X objective lenses. At high magnifications (up to 200X) the film shall be flat and in sharp focus over a minimum of 1 square inch. This means that when the optical system is focused at any point within the 6X6 inch viewing area, no refocusing will be required when viewing within a 1 inch square surrounding the point.		Pressure plate thickness = .063" (max.) Satisfactory
5.1.4 Film Measurement System Digitizer Measurement Range	Both film stages must have a measuring capability. Each of these measuring stages shall have two axis (X and Y) digitizers with a measuring range of ± 3 inches in both axis. The movement of the X-Y carriages of the two photo stages shall be measured by four digitizers (left X and Y, right X and Y) with a measuring range of six inches in both X and Y directions. The signals from the X-Y digitizers shall be processed and converted into a format acceptable for on-line computer use.	Observed.	Satisfactory
Accuracy	The prime objective of this system is to produce the highest possible accuracy over short distances (up to 1 inch) with less emphasis on accuracy over longer distances. The accuracy shall be 2 micrometers for measurements of 1 inch or under. An accuracy of at least 2 micrometers plus 1 part in 100,000 shall be provided over the entire film format.	The manufacturer's calibration certificates (Figures 3, 4, 5, and 6), indicates satisfactory accuracy.	Satisfactory
Least Count	The least count or pulse increment shall be 1 micrometer.	Observed	Satisfactory

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
Stage Orthogonality	The deviation from orthogonality of the X and Y axis of the measurement system shall be less than 5 seconds of arc.	Two methods have been used to measure the non-orthogonality angle of the TSC. The first method utilizes linear measurements made on a glass scale (Scale Method) and the second method utilizes a Ronchi grid (Grid Method). Data is contained in Table 2.	Non-Orthogonality Angle (seconds of arc) Scale Method: Left Stage: -.6 ± 1.9 — Right Stage: 3.5 ± 1.4 Grid Method: Left Stage: (Not measured) — Right Stage: 3.0 ± .9 (± values are the 95% confidence limits) Satisfactory
5.1.5 Measurement Readout	The Twin Stage Comparator is intended for on-line computer use at the customer's facility utilizing [redacted] as the central computer.		
Compatability	The contractor is authorized to substitute a measurement readout system (or digital acquisition system of his choosing) for the [redacted] equipment recommended in the Development Objectives as long as it is compatable with the in-house on-line computer equipment.	The measurement readout system was used in an actual mensuration exercise.	Satisfactory
	The contractor will provide and fabricate: (1) a control panel [redacted] 2825A or equivalent) with integral display; (2) movable cabinet (on casters) containing the necessary electronic dealers, synchronizers, buffers, special character generators, etc., to process and convert the data from the 2-axis encoders and from the control panel into a signal which will be accepted by the central computer utilizing existing programs.	Observed.	Satisfactory

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
5.1.6 Stage Illumination	A high intensity optimized condenser type light source shall be provided beneath the surface glass plate of each chip stage. This source shall be designed for and mated with the microscope to insure maximum total performance from the optical viewing system.	Observed	Satisfactory
Color Temperature	These sources shall operate at a color temperature between 2800°K to 5500°K (the apparent color temperature shall be that of white light).	Visually observed. Visually observed.	Satisfactory
	Means shall be provided for continuously varying the illumination from 50% to 100% of full intensity source without reducing the color temperature below 2800°K. The apparent color temperature will be that of white light.	Visually observed.	Satisfactory
Filters	In addition [redacted]lass neutral density filters shall be used to accommodate for the wide variety of illumination conditions required by film density variations from 0.0 to 3.0.	Filter densities have been calculated from luminance readings, taken with a Gamma [redacted]hotometer with photomultiplier and fiber optics probe.	Filter Densities: Stated / Measured Left / Measured Right .50 / .58 / .58 1.00 / .89 / .91 1.50 / 1.43 / 1.45 Satisfactory
Intensity Controls	Separate controls for varying the intensity of illumination of each separate illumination source shall be provided.	Observed.	Satisfactory
Heat	The temperature on the surface of each stage plate shall not exceed 100°F after operating at maximum intensity over an 8 hour period in an 80°F ambient termperature while a neutral density of 1.5 covers the plate. Necessary care shall be taken to assure the film is adequately cooled so as to	With the optics illumination at maximum and the diaphragm set at 10X, a film of 2.0 density was placed under the auxilary film chips, completely covering the glass platen. A thermistor was placed under	Initial Temp. (°F) / Final Temp. (°F) 79.0 Left Stage 80.8 78.2 Right Stage 80.8 (after 4 1/2 hours)

5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
	prevent dimensional changes which could affect meansuration reliability.	the film at the illuminated area and the temperature was monitored for 4 1/2 hours. The test was not run for 8 hours as the temperature values were far below the specified maximum, and a 2.0 density film was used rather than a 1.5 density filter.	Satisfactory
	A second, overall lighting system shall be provided to illuminate the entire format for general viewing and pre-selection of points to be measured. The flicker frequency shall exceed 80 Hz.	Observed (not measured).	No flicker is visible and entire format lighted effectively. Satisfactory
5.1.7 Control Console	The complete system shall be designed in accordance with correct ergonomic principles for easy, comfortable, rapid operation.	See Section 5.2.1 Human Factors	(Section 5.2.1)
Variable Drive Control	Controls shall be provided for setting a 5 to 1 (or larger) variable differential drive to couple the corresponding axis of the second stage.	The test consisted of comparing stage displacement readout information with the speed ratio set in various positions. In each case the joystick was displaced by a measured displacement angle from vertical. Averages were made of speed ratio values taken for 3 (5°, 7°, 9°) displacements in each of the 4 major directions (NWSE) and for the master control first in the left position and then in the right position, for a total of 24 measurement combinations.	STAGE SPEED RATIOS Stated Ratio / Measured Ratio 1.0 / 1.00 .8 / .78 .6 / .57 .4 / .38 .2 / .21 Satisfactory

5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
Independent Translation Control	Controls shall permit independent translation of either stage of common translation of both stages with a single "joystick".	Observed.	Satisfactory
Slewing and Fine Positioning Controls	The stage drive controls for both slewing and fine positioning shall be smooth and positive.	The test for evaluating the stage drive controls consisted of measuring the angular displacement of the joystick and the corresponding stage displacement.	Under joystick control the stage motion is unpredictable as far as speed and directional displacement (with deflection of 5° or less) are concerned. At large deflections, direction of stage motion corresponds to joystick movement. Handwheel controls permit smooth and positive fine positioning. Satisfactory
Variable Speed Control	Continously variable speed drive controls to cover the range of 5 micrometers to 5mm per second shall be provided.	The test consisted of timing stage displacements for set joystick deflection.	Under joystick control the stage move at speeds varying from 5 micrometers per second to 10 millimeters per second. Satisfactory
5.1.8 Overall Physical Factors Dimensions	The size of this comparator is to be kept at a very minimum. The length and width shall be no greater than 48 inches by 34 inches.	Measurements.	Length: 48"; Width: 34"; Knee Well: (h) - 25", (w) - 24", (d) - 22" Eyepoint to Floor: 47 3/4 $\pm$ 1" Satisfactory
Mounting and Leveling	The Comparator shall have its own stand or mounting and shall be provided with suitable casters for moving. Leveling pads or mounts that can be easily and quickly activated, shall be provided.	Set-up test.	Leveling process is somewhat difficult in that a number of dependent adjustments are required, however the requirement is infrequent. Satisfactory

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
Environment	The instrument shall be designed to operate in a normal P.I. work area. The environmental conditions in this work area will normally be held to temperatures of 72°F + 5°F And relative humidities of 55% (+15 to -5 percent).	Observed.	No problems were encountered in over 150 hours of operation. Satisfactory
Shielding	Shielding shall be provided throughout the system so that no circuits are adversely affected by RFI.	Observed (no RFI test conducted as such).	Sufficient shielding is apparently included in the construction of the electronics console to prevent RFI. Satisfactory
Human Factors Dimensions	The knee well shall be no less than 25 inches high and 24 inches wide by 22 inches deep. The eyepoint shall be approximately 47 inches from the floor when the eyepieces are in the 25° position. The viewing stage shall be approximately 32 inches from the floor. The eyepoint shall be as close to the front edge of the instrument as possible.	Measured.	Kneewell: (h) - 25" (w) - 24" (d) - 22"; Eyepoint: 47 3/4 ± 1". Satisfactory
5.1.9 Reliability and Service Usage	The Comparator and related equipment shall be designed to withstand service usage, under normal operating conditions, for a period 2000 hours (5 hours per day operation) without significant degradation of performance, and with only minor maintenance due to normal expendable replacement parts. Mean time between failures shall be no less than 200 operational hours.	A one hundred and fifty hour operation test (made during tests of optics, illumination, etc.) was conducted.	No failures in equipment operation have been observed in approximately 150 hours, and therefore the system is judged to be of the desired quality. Satisfactory
5.1.10 Reliability and Maintainability	These factors shall be major factors in the fabrication of this instrument.	Observed.	The TSC has been well designed and the reliability and maintainability requirements are satisfied. Satisfactory
Access Design	The design shall permit: (1) ease of assembly and disassembly, (2) ready access to potential trouble sources, (3) maintenance with tools and equipment normally available to	Observed.	The electronics rack provides easy access to the chassis for servicing. Test points are not provided external to the chassis, but are accessible by the use of extender cards within the

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT - CONCLUSION
	maintenance personnel, and (4) external test points.		chassis. Overall design is considered very satisfactory. The construction of the TSC allows access to all components which may need servicing, including lamps, electronics components and fuses. Satisfactory
High Voltage	High voltage areas shall be properly interlocked for maintenance purposes. These areas shall be properly labeled. Circuits operating with an open circuit potential of 30 volts or more and a capability for delivering 2.5 peak milliamperes or more into a short circuit shall be considered hazardous and shall be labeled and interlocked.	Observed.	Satisfactory
5.1.11 Miscellaneous Manuals and Spare Parts	At the time of delivery of the equipment, the contractor shall also provide the following: (1) Operator's Instruction Manual, (2) Maintenance Manual (including schematics, (3) Recommended spare parts lists, including the cost of each item and the total parts package cost.	Observed.	Satisfactory
Electric Hazard	The unit must be grounded and free of all electric shock hazards. All electrical circuits shall be properly fused and spare fuses shall be supplied with the instrument.	The leakage current and voltage was measured with the unit ungrounded.	The test showed: (frame to ground) Potential - 56 v Current - 8.5 ma. This exceeds the .75 ma level set by the USA Standard for Leakage Current for Appliances, sponsored [redacted] Satisfactory
Warning Light	A warning light must be provided to show when the power supply to the system is switched on.	Observed.	Provided. Satisfactory

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5.1 Acceptance Tests (continued)

ITEM	DESIGN OBJECTIVES SPECIFICATIONS	TEST METHOD	RESULT- CONCLUSION
Controls	All switches and controls must be properly and clearly marked, conveniently located, and readily accessible to the operator.	Human Factors Evaluation (Section 5.1.13)	Unsatisfactory
Stage Protection	Limit switches shall be located at the extremes of travel of the X-Y carriages of both film stages to prevent damage to the system.	Observed	Satisfactory
Interface	The contractor shall be responsible for all electronic interfacing, logic circuitry, and cabling between the digitizers, encoders, digital display, and on-line computer.	Observed.	Satisfactory
5.1.12 Noise	The maximum equipment noise energy levels shall not exceed Noise Criteria Curve 40 per MIL-STD 803 A-2. Measurements shall be referenced to the normal head position of the average operator.	Observed (not measured).	The maximum sound level is judged to be considerably below the levels given in N.C. Curve 40. Satisfactory
5.1.13 General Construction Safety Items	The instrument shall be free of all sharp corners. No exposed surface of the instrument shall exceed 110°F unless protection is provided to avoid bare skin contact.	Observed and measured.	All surfaces are relatively smooth. The following items reach temperatures above 110°F: 1) backlighted power switch (145°F), 2) function indicator lights (111°F), and the handwheel control gear boxes (112°F). Unsatisfactory
Guards	Guards shall be provided on all moving parts on which personnel may become injured or entangled. Nominal openings in any guard must not exceed 1/2 inch.	Observed.	No moving parts are exposed which may cause serious damage, however, the minimum separation between stages is .25 inch. If some part of the body was accidentially placed between the stages, physical injury could occur. Safe practice by the operator would probably avoid the potential hazard. Satisfactory
Human Engineering	Unless specifically enumerated in this specification, the instrument shall comply with Section 4.0 of the Human Engineering Design Guide for Image Interpretation Equipment [redacted]	A comparison was made between equipment characteristics and Design Guide requirement.	Items described below in paragraph 5.1.14.

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5.1 Acceptance Tests (continued)

5.1.14 Human Factors Considerations

(Most information taken or quoted from the Final Report Human Factors Evaluation, Twin-Stage On-Line Comparator [redacted] November 1969 [redacted]

Film Loading

Film loading and unloading are difficult to accomplish as the upper film platen is not hinged or fastened, requiring that it be held out of the way during the loading or unloading process. Clearance problems exist unless the stages are as far forward or outward as possible.

Potential Glass Platen Breakage

The lower glass platen is loose in the holder and when in contact with the upper platen prior to the upper platen being raised, it will stick to the upper platen (molecular attraction). This condition may possibly lead to breakage as the lower glass falls back to the metal frame.

Reticle Fusion

During the evaluation, the Comparator was loaded with a stereo pair and the recommended focusing procedures followed. The reticles were easily focused but some difficulty was encountered in fusing them. Once the stereo model was achieved and the reticles fused with the pointing dot on top of an image, the "floating" of the dot was attempted. This failed as the individual dots reappeared.

Omitted Labels

Labels omitted on 1) hand cranks which rotate the film stages, 2) knobs which provide objective lens focus adjustment, and 3) joystick and handwheels, which control stage motion. These controls should be labeled. All other controls are labeled.

Incorrect Label

The filter density pointer control is labeled "Filters" and the repsective switch positions 1, 2, 3, 4, correspond to filter densities on 0.0, 0.5, 1.5, and 2.0 respectively. The function of the control would be more explicit if the labels read Filter Density, 0.0, 0.5, 1.5, and 2.0.

Improvement Areas

All controls on the comparator are adequate for their intended function, however several improvements could be made to increase operational efficiency: 1) eliminate "slop" in hand crank and worm gear assembly on film rotation stages, 2) increase position detents for diaphragm control, and replace circular knob with a bar shaped knob, 3) relocate servo power toggle switch to a position not subject to accidential shut off, 4) change servo power switch color from red to blue, and 5) change main power switch color from red to white.

5.2 Performance Tests

ITEM	PERFORMANCE TEST	TEST METHOD	RESULTS
5.2.1 Pointing Efficiency (Joystick vs. Handwheels)	The efficiency of the pointing function is compared, using the two controls for stage movement. The emphasis is on pointing efficiency for small displacements (in the order of 300 micrometers or less).	To compare the pointing efficiency obtained both before and after Comparator modification (addition of X-Y-wheels controls) the following tests was performed: 1. A dot grid containing 4 dots, approximately 6 micrometers in diameter, and arranged in a rectangular shape is set up as the test target. 2. A stopwatch is started when the sequential pointing (4 points) exercise is begun, and then is stopped when the locations of the points have been used in computer mensuration calculations yielding the final rectangular dimensions and the enclosed area. 3. Thirty repetitions of the 4-point target measurements were made as a representative sample. 4. Comparison of the average times obtained, using the respective controls (joystick-handwheels) allows the efficiency to be expressed as a percentage.	<u>Average Time</u> (Sec) Joystick: Handwheels: 109.9 ± 5.3 81.1 ± 1.0 (95% Confidence Intervals) Improvement: 28.8 sec, or 26.2% Data is contained in Table 3, Pointing Efficiency and Pointing Precision.

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5.2 Performance Tests (continued)

ITEM	PERFORMANCE TEST	TEST METHOD	RESULTS
5.2.2 Pointing Precision (Joystick vs. Handwheels)	The pointing precision, available with the two types of controls, is compared by making actual measurements both linear and area. The emphasis is on pointing precision for relatively small displacements (in the order of 300 micrometers or less).	To compare the pointing precision obtained using the respective stage motion controls the pointing exercise described above was used. The data obtained yields both linear dimensions and the area of the target (converted to ground size units). A statistical analysis was made of the average values and the variances obtained using the respective controls. A total of 30 pointings were used as a representative sample. Data is contained in Table 3.	see below
5.2.3 Illumination System Sub-Stage Illumination	The test was to determine the luminance produced by the sub-stage illumination system.	The illumination system was tested using a Gamma Model 2020 Photometer with a fiber optic's probe and various attachments. The Photometer and probe was calibrated with the Gamma 100 foot-lambert source prior to the test. Ground glass with neutral density of .05 was placed on the film platen in order to provide a diffuse surface for luminance measurements. Readings were taken at 4 points on each platen.	Luminance Range 159 - 252 foot-lamberts The system is considered adequate for the intended use.

Results for 5.2.2:

Linear Measurements Dimension (ft)				(Controls)	Values
S	E	N	W	Average	
22.5	23.7	22.5	23.7	-J-	484 (ft^2)
22.6	23.7	22.5	23.7	-H-	484 (ft^2)
				Variance	
.04	.16	.04	.04	-J-	43.6(ft^4)
.01	.04	.01	.09	-H-	9.6(ft^4)
				Pooled Variance	
.07 (ft)				-J-	
.04 (ft)				-H-	
				Standard Deviation (Precision)	
.26 (ft)				-J-	6.6 (ft^2)
.20 (ft)				-H-	3.09 (ft^2)

For both linear and area measurements the handwheels (H) yield a better precision.

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5.2 Performance Tests (continued)

ITEM	PERFORMANCE TEST	TEST METHOD	RESULTS
Film-Plane Illumination	Luminance available at the film plane was also measured.	The maximum output of the luminance sources was measured using the equipment and method described previously. Readings were made with bulb usage under four hours, and with various diaphram and filter combinations. The data is listed in Table 4, Luminance Available at Film Plane.	Maximum (Luminance) Minimum Left Stage: 28,500 1,020 Right Stage: 22,500 800
Optical Illumination	Luminance through the optics was also measured.	The light passing through the optical train was measured with a scanning micrometer eyepiece containing a fiber optics sensor. An additional test was necessary to measure light loss through the 10X objective, since the eyepiece was removed to install the micrometer eyepiece. Measurements were taken at 200X magnification, through the total optical train with no film on the platen.	Luminance (apparent footlamberts) Left Stage: 9.9 Right Stage: 7.1
5.2.4 Optics	The focus adjustment of the objectives was checked after initial tests showed the adjustment inadequate for the 1.3X and 3X lenses.	The focus adjustment capabilities of the objectives was tested by focusing on a resolution target (far within the resolving power limits of the TSC) and observing whether the target could be focused sharply or not.	After initial mechanical readjustment, the right stage 1.3X objective focus adjustment still reaches the upper limit of travel just before good focus is achieved.

5.2 Performance Tests (continued)

ITEM	PERFORMANCE TEST	TEST METHOD	RESULTS
Focus Check	As an additional test, the resolution capabilities of the TSC was measured after the stage was displaced. The results show areas out of focus after stage displacement.	A resolution target was placed under each corner of both stages Initial focus adjustment was made on the right front corner and then the remaining corners displaced and the resolving power noted.	Stages: 3 4 / 2 1 and 7 8 / 6 5. Points 1 and 5 are initially in focus. Point/Resolving Power (lp/mm) 1: 854, 2: 537, 3: 854, 4: 854, 5: 760, 6: 760, 7: -, 8: 604 NOTE: Point #7 is completely out of focus.
5.2.5 Physical Characteristics	The physical characteristics of TSC have been measured.	Measurements.	Weight: Comparator - 735 lb; Electronics - 300 lb Power Requirements: less than 600 watts (5 amperes @ 117 vac) Dimensions (in) H W D: Comparator - 52 48 34 Electronics - 52 23 26 Writing Surface - - 17 10

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5.3 Engineering Evaluation

5.3.1 Construction

The construction of the TSC is sufficiently rigid so that floor vibrations do not cause visible image motion, even at 200X magnification.

5.3.2 Backlash

The handwheel controls have some gear backlash, however no measurement backlash (displacement difference vs. direction) was observed. Another feature was discovered which may cause measurement errors. If excessive hand pressure is applied to the handwheels the film stage may be physically displaced without a change in position being noted by the photo-electrical counter. An apparent position change in the order of $\pm$1-2 micrometers was observed on the right stage Y-axis. Backlash on the other 3 axis could not be detected.

5.3.3 Drift

As both upper and lower glass platens are held only by frictional forces (within the frame) there is some potential for undetected motion of the film target. A test was made to measure the "drift". An initial point was selected and the drift displacement measured by using the Comparator. A drift of approximately 9 micrometers occurred during a 2 hour period (right stage).

5.3.4 Servicing

The electronics rack provides easy access to the classics for servicing. Test points are not provided external to the chassis but are accessible by use of extender cards.

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TABLE 1. RESOLUTION DATA

EYEPIECE	OBJECTIVE	ZOOM	SYSTEM POWER	LINES/MM LEFT PATH RESOLUTION	LINES/MM RIGHT PATH RESOLUTION
6X	1.3X	1.0	7.8	67.44	67.44
		1.5	11.7	87.96	87.96
		2.0	15.6	134.60	120.0
	3.0X	1.0	18.0	134.60	134.60
		1.5	27.0	169.68	190.96
		2.0	36.0	213.84	213.84
	6.0X	1.0	36.0	268.8	268.8
		1.5	54.0	427.2	338.4
		2.0	72.0	480.0	427.2
	10.0X	1.0	60.0	480.0	480.0
		1.5	90.0	604.8	537.6
		2.0	120.0	679.2	604.8
10X	1.3X	1.0	13.0	95.28	95.28
		1.5	19.5	120.0	106.80
		2.0	26.0	120.0	120.0
	3.0X	1.0	30.0	213.84	213.84
		1.5	45.0	240.0	240.0
		2.0	60.0	268.8	240.0
	6.0X	1.0	60.0	427.2	338.4
		1.5	90.0	480.0	480.0
		2.0	120.0	537.6	480.0
	10.0X	1.0	100.0	604.8	604.8
		1.5	150.0	760.8	679.2
		2.0	200.0	854.4	760.8

TABLE 2. ORTHOGONALITY DATA

(Scale Method)

Left Stage e = 1.00002

	X (micrometers)	Xy (X.1/e)	Y (micrometers)	Yx (Y.e)	Angle (Seconds of Arc)
1	84817	84815	84884	84886	- 10
2	84810	84808	84885	84887	+ 4
3	84813	84811	84885	84887	- 2
4	84814	84812	84885	84887	- 4
5	84815	84813	84885	84887	- 6
6	84814	84812	84882	84884	+ 2
7	84815	84813	84885	84887	- 6
8	84816	84814	84883	84885	- 4
9	84815	84813	84884	84886	- 4
10	84814	84812	84884	84886	+ 2
11	84817	84815	84884	84886	- 10
12	84813	84811	84883	84885	+ 4
13	84814	84812	84886	84888	- 8
14	84814	84812	84883	84885	+ 2
15	84815	84813	84883	84885	0
16	84813	84811	84886	84888	- 6
17	84817	84815	84883	84885	- 6
18	84811	84809	84884	84886	+ 4
19	84811	84809	84884	84886	+ 6
20	84813	84811	84883	84885	+ 4
21	84810	84808	84886	84888	+ 8
22	84815	84813	84882	84884	+ 2
23	84816	84814	84880	84882	+ 8
24	84814	84812	84883	84885	+ 2
25	84810	84808	84887	84889	+ 4

Average Angle = 0.6 seconds of arc

Standard deviation = .55 seconds

95% Confidence Limits = -.6 ± 1.0 seconds of arc

Table 2. (continued)

(Grid Method)

<u>Right Stage</u> e = 1.00001

	X_1	$Y_1.e$	$X_1/Y_1.e$ (a)	X_2	$Y_2.e$	$X_2/Y_2.e$ (b)	Angle $\frac{a-b}{2}$ (sec) (.4848136)
1	409	135404	.00302	456	149694	.00305	- 3
2	408	135404	.00301	455	149694	.00304	- 3
3	413	135404	.00305	454	149694	.00303	+ 2
4	409	135404	.00302	455	149694	.00303	- 1
5	452	149694	.00302	444	149694	.00296	+ 5
6	451	149694	.00301	446	149694	.00298	+ 3
7	451	149694	.00301	444	149694	.00297	+ 4
8	450	149694	.00301	444	149694	.00297	+ 4
9	454	149694	.00303	446	149694	.00298	+ 5
10	454	149694	.00303	446	149694	.00298	+ 5
11	454	149694	.00303	448	149694	.00299	+ 4
12	451	149694	.00301	446	149694	.00298	+ 3
13	456	150001	.00304	466	155406	.00300	+ 4
14	457	150001	.00305	466	155406	.00300	+ 5
15	456	150001	.00304	466	155406	.00300	+ 4
16	458	150001	.00305	467	155406	.00301	+ 4
17	380	125810	.00302	458	153613	.00298	+ 4
18	378	125810	.00300	460	153613	.00299	+ 1
19	379	125810	.00301	461	153613	.00300	+ 1
20	379	125810	.00301	460	153613	.00299	+ 2
21	371	122873	.00302	428	144587	.00296	+ 6
22	369	122873	.00300	428	144587	.00296	+ 4
23	368	122873	.00299	429	144587	.00297	+ 2
24	370	122873	.00301	430	144587	.00297	+ 4
25	449	147450	.00305	435	145771	.00298	+ 7

Average Angle = 3.0 seconds of arc

Standard Deviation = 2.5 seconds of arc

95% Confidence Limits = 3.01 $\pm$.9 seconds of arc

Table 2. (continued)

(Scale Method)

Right Stage e = 1.00001

	X (micrometers)	Xy (X.1/e)	Y (micrometers)	Yx (Y.)	Angle (Seconds of Arc)
1	86731	86730	82923	82924	- 2
2	86728	86727	82923	82924	+ 4
3	86732	86731	82919	82920	+ 8
4	86730	86729	82921	82922	+ 4
5	86730	86729	82923	82924	- 2
6	86729	86728	82922	82923	+ 6
7	86729	86728	82920	82921	+ 10
8	86731	86730	82920	82921	+ 6
9	86728	86727	82921	82922	+ 10
10	86728	86727	82923	82924	+ 4
11	86729	86728	82924	82925	0
12	86731	86730	82922	82923	+ 2
13	86728	86727	82924	82925	+ 2
14	86728	86727	82923	82924	+ 4
15	86732	86731	82923	82924	- 4
16	86732	86731	82922	82923	0
17	86728	86727	82921	82922	+ 10
18	86732	86731	82920	82921	+ 4
19	86730	86729	82921	82922	+ 4
20	86730	86729	82923	82924	- 2
21	86730	86729	82920	82921	+ 6
22	86731	86730	82923	82924	- 2
23	86730	86729	82921	82922	+ 4
24	86734	86733	82920	82921	+ 6
25	86731	86730	82920	82921	+ 6

Average Angle = 3.5 seconds of arc

Standard deviation = 4.0 seconds

95% Confidence Limits = 3.5 ± 1.4 seconds of arc

TABLE 3. POINTING EFFICIENCY AND PRECISION

DATA

HAND-WHEEL CONTROLS

POINT TRIAL	TIME (Min:Sec)	DIMENSION (Ft.) S	E	N	W	AREA (Sq. Ft.)
1	1:26.7	22.6	23.6	22.6	23.6	482
2	1:22.6	22.6	23.6	22.4	23.6	478
3	1:19.6	22.6	23.7	22.5	23.7	483
4	1:26.5	22.5	23.5	22.5	23.9	484
5	1:21.4	22.6	23.7	22.6	23.8	485
6	1:21.2	22.6	23.7	22.4	23.7	482
7	1:16.5	22.7	23.7	22.5	23.5	480
8	1:20.2	22.6	23.7	22.5	23.7	484
9	1:19.8	22.5	23.6	22.4	23.7	481
10	1:24.8	22.6	23.7	22.5	23.6	483
11	1:18.2	22.6	23.6	22.7	24.1	487
12	1:20.0	22.8	23.6	22.8	23.6	485
13	1:20.0	22.7	23.4	22.5	23.6	481
14	1:18.8	22.6	23.7	22.4	23.9	487
15	1:20.0	22.7	23.0	22.5	24.0	493
16	1:22.0	22.7	23.3	22.8	23.6	484
17	1:21.6	22.8	23.6	22.6	24.0	487
18	1:22.6	22.4	23.9	22.4	23.7	483
19	1:22.5	22.7	23.6	22.4	23.7	483
20	1:16.6	22.6	24.1	22.5	23.4	488
21	1:22.8	22.7	23.6	22.5	23.7	484
22	1:28.2	22.6	23.7	22.5	23.6	481
23	1:17.2	22.6	23.4	22.5	22.5	477
24	1:23.0	22.6	23.7	22.5	23.7	483
25	1:25.8	22.6	23.7	22.5	23.8	484
26	1:24.9	22.5	23.7	22.5	23.7	486
27	1:17.2	22.5	23.6	22.5	23.8	483
28	1:16.6	22.5	23.6	22.5	23.8	483
29	1:18.5	22.7	23.7	22.5	23.9	486
30	1:17.0	22.4	23.6	22.5	23.8	482
Average	1:21.1	22.6	23.7	22.5	23.7	484
Standard Deviation	3.3	.1	.2	.1	.3	3.1

SUMMARY (AVERAGES)
(95% Confidence Limits)

TIME: 81.1± 1.0 sec.

DIMENSIONS: (Ft.)

S: 22.6± .03

E: 23.7± .06

N: 22.5± .03

W: 23.7± .09

AREA: 484± .9 sq. ft.

Table 3. (continued)

JOYSTICK CONTROLS

POINT TRIAL	TIME (Min:Sec)	DIMENSION (Ft.) S	E	N	W	AREA (Sq. Ft.)
1	2:34.2	22.8	23.7	22.7	23.6	485
2	2:01.6	22.5	23.9	22.4	23.7	484
3	2:51.0	22.4	23.8	22.4	23.7	478
4	1:55.2	22.8	24.3	22.3	24.0	494
5	2:08.2	22.4	23.3	22.6	23.8	481
6	1:55.8	22.4	24.3	22.6	23.8	487
7	1:41.1	22.5	23.9	22.8	24.2	499
8	2:31.4	22.6	23.9	23.1	23.7	493
9	2:28.8	22.8	23.7	22.6	23.7	482
10	1:48.8	22.6	24.2	22.6	23.6	489
11	1:38.2	22.6	24.2	22.6	23.7	489
12	1:36.0	22.0	23.6	22.4	23.8	479
13	1:47.4	22.4	23.5	22.4	23.6	479
14	1:34.4	22.6	24.2	22.3	23.8	486
15	2:03.8	22.5	23.1	22.6	23.5	477
16	1:34.6	22.5	23.6	22.7	23.5	486
17	1:57.6	22.6	24.4	22.6	24.2	502
18	1:29.2	22.6	23.5	22.4	23.2	475
19	1:39.2	22.4	23.6	22.7	23.8	483
20	1:35.6	22.5	23.9	22.5	23.8	486
21	1:39.0	22.4	24.0	22.4	23.6	482
22	1:40.2	22.2	23.0	22.7	23.6	475
23	1:36.3	22.6	23.4	22.4	23.8	483
24	1:56.8	22.6	23.9	22.4	23.9	488
25	1:36.0	22.5	23.3	22.4	23.8	477
26	1:48.2	22.7	23.7	22.5	23.7	483
27	1:42.4	22.5	23.6	22.7	24.0	487
28	1:40.6	22.6	23.4	22.4	23.4	477
29	1:42.6	22.0	23.2	22.6	23.9	484
30	1:44.4	22.8	23.7	22.5	23.8	484
Average	1:49.9	22.5	23.7	22.5	23.7	484
Standard Deviation	17.1	.2	.4	.2	.2	6.6

SUMMARY (AVERAGES)
(95% Confidence Limits)

TIME: 109.9 ± 5.3 sec.

DIMENSIONS: (Ft.)

S: 22.5 ± .06

E: 23.7 ± .12

N: 22.5 ± .06

W: 23.7 ± .06

AREA: 484 ± 2.0 sq. ft.

TABLE 4. LUMINANCE AT FILM PLANE

DIAPHRAM	FILTER	LEFT (fL)	RIGHT (fL)
10	1	28,500	22,500
6	1	27,000	20,750
3	1	23,000	15,500
1.3	1	15,000	10,000
10	2	7,200	6,100
10	3	3,525	2,900
10	4	1,020	800

Filter Densities (calculated from luminance readings).

	Left	Right	% Difference
F 2	0.579	0.575	0.69
F 3	0.894	0.910	1.79
F 4	1.430	1.450	1.38

Note: 1) Readings made with bulbs with 0-4 hours use.
2) All readings made through ground glass with neutral density of 0.05
3) Instrument used: Gamma [redacted] Photometer with photomultiplier and fiber optics probe.

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